WATER POLL. RES. J. CANADA:
VOLUME 20, NO. 1, 1985

DISTRIBUTION OF ORGANOCHLORINE PESTICIDES AND PCB's BETWEEN AQUEOUS AND SUSPENDED SEDIMENT PHASES IN THE LOWER GREAT LAKES REGION

Robert C. McCrea, John D. Fischer and Kenneth W. Kuntz

Water Quality Branch
Inland Waters Directorate
Canada Centre for Inland Waters
Burlington, Ontario, L7R 4A6

ABSTRACT

Suspended sediment and extracts of the aqueous phase were collected in 1981 at eleven locations in the Lower Great Lakes Region and analyzed for 17 organochlorine pesticide residues and PCB's. Mirex, and p,p'-DDE when found were predominantly in the suspended sediment fraction, whereas α-BHC, γ-BHC, dieldrin, endrin, p,p'-TDE and trans-chlordane were most abundant in the aqueous phase. Several pesticide residues, notably cis-chlordane, p,p'-DDT and p,p'-methoxychlor were found to have variable distribution characteristics between the suspended sediment and aqueous phases. The greater proportion of organochlorine pesticides present in Lake Erie and the Niagara River were found in the aqueous phase samples, which contained at least 90% of the total pesticide concentration at 5 of the 6 stations sampled. Virtually all of the organochlorine contaminants present in Lake Ontario were found in the aqueous phase, which contained 100% of the pesticides and 91% of total PCB's. Similar results were obtained for the St Lawrence River.

INTRODUCTION

Studies of organochlorine pesticides and PCB's in the Lower Great Lakes and connecting channels have revealed that high concentrations of these compounds are sorbed to bottom (Frank et al., 1979; Holdrinet et al., 1978) and suspended sediments (Warry and Chan, 1981; Kuntz and Warry, 1983). The aqueous phase, however, has been largely ignored since concentrations in raw water samples have generally been below the analytical detection limit of gas chromatographic systems when a traditional two-litre sample is used (Chan, 1980; Chan, 1977; Kuntz and Chan, 1982).

When organic contaminant concentrations found on suspended sediment are reported, the large quantity of water filtered to obtain the sediment is seldom considered. Nineteen organochlorines contaminants have been routinely monitored in the Niagara River (Kuntz, 1984). During the sampling period, 1979 to 1981, the average suspended sediment load was 8.4 mg/L and the mean concentration of organochlorine pesticides and PCB's found on the suspended sediment ranged from 1 to 718 ng/g. When these organochlorine concentrations are calculated in terms of their ambient concentrations in water (ng/L), levels below the analytical detection limit for water analysis are obtained. This gives rise to the question as to whether the aqueous or suspended sediment phase is the major carrier of trace organic contaminants in natural waters.

A large volume (200 litre) aqueous phase liquid-liquid extractor (APLE) designed by the Inland Waters Directorate (IWD), Environment Canada, has effectively reduced the detection limit by two orders of magnitude below that of the traditional two-litre sample, providing a more sensitive method of investigating trace organic contaminants in natural waters (McCrea and Fischer, 1984). As a result, it was decided that a preliminary study should be conducted to investigate the distribution of trace organic contaminants between the aqueous and suspended sediment phases in both lotic and lentic systems. The stations chosen in the Lower Great Lakes Region allowed for the investigation of a variety of river and lake sites in an area where trace organic contaminants were known to be present.

87-05296/

METHOD

Eleven stations in the Lower Great Lakes Region were sampled during the course of this study. Lotic samples were obtained from five stations on the Niagara River and two stations on the St Lawrence River (Fig. 1). Lentic systems were sampled at one station on Lake Erie and three stations on Lake Ontario.

Initial sampling was performed on four dates during March, 1981, at Niagara-on-the-Lake (NOTL) in conjunction with an ongoing IWD suspended sediment sampling program. The sampling system was housed in a water intake shed and set up to collect samples 30 m from shore, at a depth of 13 m, using a polyethylene intake tube suspended 6 m off the river bottom (Warry and Chan, 1981). The intake tube was connected to a March magnetic-drive submersible pump. All wetted parts were non-contaminating and the design prevented the risk of lubricant seepage into the pump head assembly.

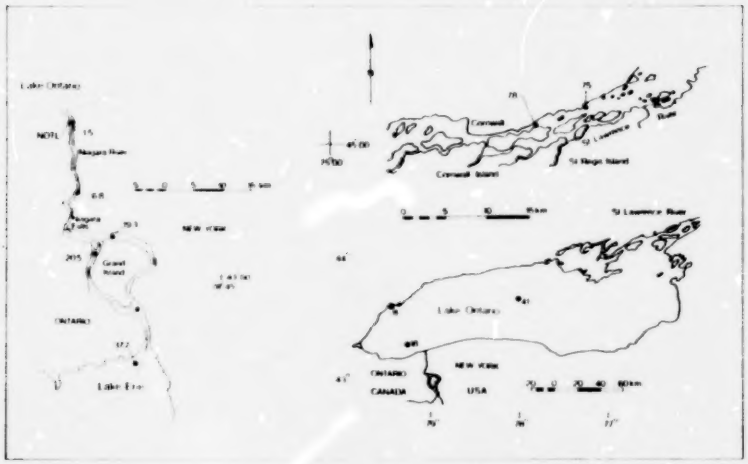

Figure 1 Sampling locations in the Lower Great Lakes Region.

A large volume of water (approximately 8,000 L) was delivered at a rate of 6 litres per minute to a Westfalia continuous flow centrifuge to recover the suspended sediment. These centrifuges exert a maximum force of 9500 g. Analyses of samples containing up to 70% of total solids with particle sizes finer than 0.2 micron have shown that the recovery of such suspended sediment is 90 to 95 percent effective (Thomas and McMillan, 1978). Filtration of 26 raw and centrifuged water samples collected over a one year period demonstrated that the mean recovery of suspended sediment from Niagara River water using this centrifugation system was 89 percent. Centrifuge bowls containing the sediment were later returned to the laboratory for further processing. The centrifuge effluent, referred to as the aqueous phase in this report, was extracted on site using the APLE. An evaluation of the APLE system, based on replicate spikes at three concentrations, has shown that the mean recovery of 18 organochlorine contaminants ranged from 70-123%, with an overall mean recovery of 92% (McCrea and Fischer, 1984).

The APLE extraction drum was filled with a subsample of centrifuge effluent to obtain a standard working volume of 200 litres. Eight litres of pesticide grade dichloromethane were subsequently added to the drum before the recirculating pump was turned on to initiate extraction.

After 90 minutes the pump was turned off to allow the solvent to settle out of the sample water. The solvent was drained back into the original amber solvent bottles after waiting 120 minutes for separation to take place. A small volume of sample water was included during the draining process to retard volatilization of the solvent. Since dichloromethane is slightly soluble in water (1.5% V/V), approximately 3 of the original 8 litres of solvent were not recovered. The extracts were then stored at 4°C to minimize possible degradation of the contaminants. (Environment Canada, 1979).

In the laboratory, each aqueous extract was dried using an 8 cm column of anhydrous sodium sulphate which was muffled overnight at 650°C. Approximately 700 mL of the anhydrous extract was added to a one litre round-bottom flask containing 40 mL of iso-octane. The extract was roto-evaporated at 40°C under vacuum to a volume of 50 mL. Additional 700 mL aliquots were similarly roto-evaporated. After all of the dichloromethane was evaporated, the sample was further concentrated to 4 mL in iso-octane. The concentrated extracts were eluted into two fractions using column chromatography with 3% water deactivated silica gel as the stationary phase and hexane and benzene as the mobile phase. Analyses were performed using two packed columns and a capillary column equipped with electron capture dectectors (Environment Canada, 1979).

Suspended sediment samples were removed from the centrifuge bowls and later filtered, dried and homogenized (Warry and Chan, 1981). The homogenized sediment samples were subsequently extracted, filtered through celite, dried and roto-evaporated as described in the Analytical Methods Manual (Environment Canada, 1979). Fractionation of the concentrated extracts was carried out in the same manner as the aqueous extracts. The resulting fractions were reduced by roto-evaporation, adjusted to a standard volume and subsequently analyzed on a single packed and capillary columns equipped with electron capture detection.

After initial sampling was completed, the same general method was used to sample ten stations from the Department of Fisheries and Oceans research vessel CSS Advent. Cruise schedules allowed for a single sampling of two stations on the St Lawrence River June 17-18, 1981 and three stations on Lake Ontario July 1-3, 1981. Niagara River and Lake Erie stations were sampled on three separate occasions: May 6-14, July 10-16 and October 26-November 7, 1981. Samples were collected at a depth of 1-2 m, with a March submersible pump of the design used at NOTL. Two portable Westfalia continuous flow centrifuges were used to collect suspended sediment samples at the St Lawrence River and Lake Ontario stations and one additional separator was used to sample the Lake Erie and Niagara River stations. Extraction of trace organic contaminants from the aqueous phase and the processing of suspended sediment samples were performed aboard ship in a manner similar to that used for Niagara-on-the-Lake samples.

The concentrations of the various organochlorine contaminants sorbed to suspended sediment were calculated in terms of the amount present per litre of raw water, and are expressed in ng/L. Both the aqueous and suspended sediment data from the Lake Erie and Niagara River stations were averaged to obtained mean station concentrations for each contaminant. Since the Lake Ontario stations were sampled on only one occasion, mean aqueous and suspended sediment concentrations for the three stations were calculated. Mean concentrations for the two St Lawrence River stations were similarly determined.

RESULTS

Hexachlorocyclohexane

The hexachlorocyclohexane isomers (α and γ-BHC) had the highest total concentration of all contaminants detected during this study. A marked increase in the concentrations of both isomers was observed from the Lake Erie station downstream to station 1.5 located adjacent to the former NOTL water intake plant, near the mouth of the Niagara River (Fig. 2). Both isomers were found to be present almost exclusively in the aqueous phase, with this component accounting for at least 94 percent of the total concentration present at all stations. The concentration of α-BHC was approximately five times greater than γ-BHC (lindane) at all stations except NOTL.

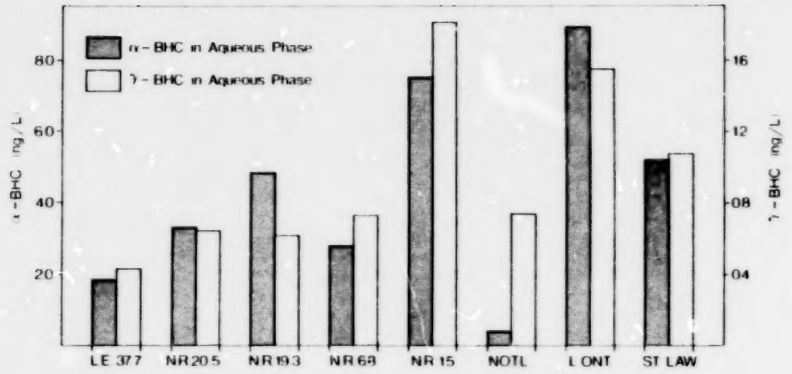

Figure : Distribution of α- and γ- BHC in aqueous phase samples from the Lower Great Lakes Region, 1981.

Chlordane

Trans-chlordane was found exclusively in the aqueous phase at the Lake Erie and Niagara River stations with concentrations ranging from .001 to .005 ng/L. The exception to this was the NOTL station where .08 ng/L of this contaminant was found, 24 percent of which was present in the suspended sediment component. The concentration of cis-chlordane was for the most part greater than that of the trans-isomer, reaching a high of .08 ng/L at both station 19.3 and NOTL. The distribution of the cis-isomer was found to be highly variable, as the percentage of this compound present in the aqueous phase was 7 and 79 percent at stations 19.3 and NOTL respectively.

Chlordane was not detected in any of the Lake Ontario samples, however, .004 ng/L of trans-chlordane was found exclusively in suspended sediment phase of the St Lawrence River.

DDT and Metabolites

DDT mainly comprises the two isomers p,p'-DDT and o,p'-DDT. The o,p'-isomer was detected only at stations 20.5, NOTL and in the St Lawrence River, at concentrations of .012, .029 and .011 ng/L respectively. The distribution of o,p'-DDT was found to be highly variable. It was detected solely in suspended sediment phase at station 20.5; evenly distributed between the two phases at NOTL and present only in the aqueous phase in the St Lawrence River.

The p,p'-isomer was found at all stations, and virtually all of this contaminant was present in the aqueous component of the Lake Erie samples. Over the course of the Niagara River, both the total concentration of p,p'-DDT and the percentage of the contaminant in the suspended sediment phase increased in a downstream direction (Fig. 3). At station 20.5, the total concentration of p,p'-DDT was .064 ng/L, 21 percent of which was present in the suspended sediment phase. The concentration increased to .14 ng/L at station 1.5 with 87 percent of the contaminant present in the suspended sediment component. At the NOTL station, the distribution of p,p'-DDT between the two phases differed greatly from results obtained at station 1.5, as 70 percent of the contaminant was found in the aqueous component.

Analyses of the Lake Ontario and St Lawrence River samples indicated that 100 and 77 percent of the p,p'-DDT was present in the aqueous phase respectively.

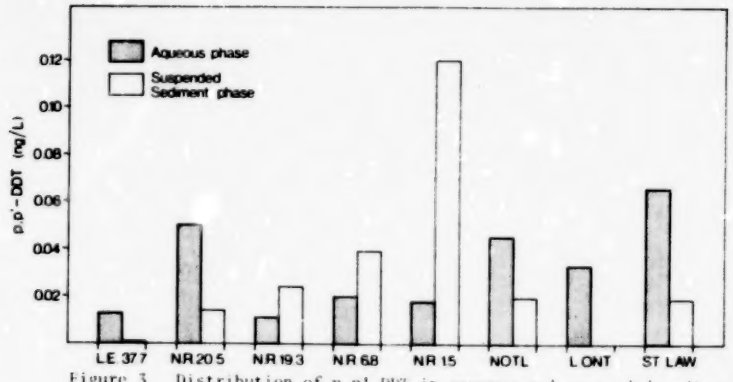

Figure 3 Distribution of p,p'-DDT in aqueous and suspended sediment samples from the Lower Great Lakes Region, 1981.

The concentrations of the two major metabolic products p,p'-TDE and p,p'-DDE were roughly the same as their parent compound p,p'-DDT. The greater proportion of p,p'-TDE was found in the aqueous phase at all stations except station 6.8, where the concentration in the suspended sediment component reached a maxima (Fig. 4). Despite the fact that p,p'-TDE was found at NOTL and station 1.5, it was not detected in the Lake Ontario samples. The bulk of p,p'-DDE was present in the suspended sediment fraction at all stations except Lake Ontario were it was found mainly in the aqueous phase.

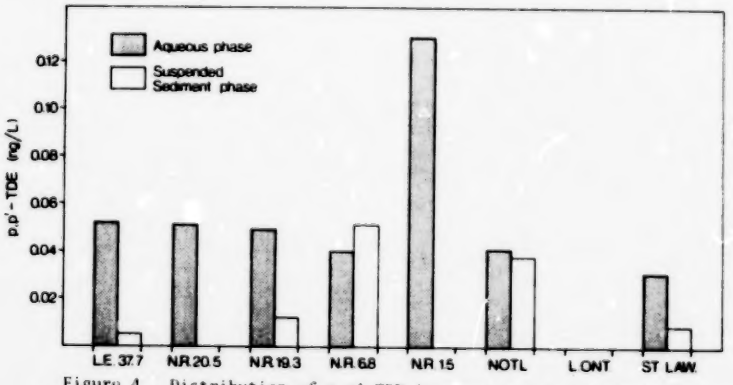

Figure 4 Distribution of p,p'-TDE in aqueous and suspended sediment samples from Lower Great Lakes Region, 1981.

Aldrin and Dieldrin

Aldrin was not detected in any of the Lake Erie, Niagara River, or Lake Ontario samples. Although this compound is readily biotransformed to dieldrin, it was detected in the aqueous phase of the St Lawrence River.

The mean concentration of dieldrin was constant in the Niagara River downstream from Lake Erie, (Fig. 5) but individual values varied up to 20 fold both within and between stations. The distribution of this contaminant was also found to remain relatively constant at all stations, with 75 percent or more existing in the aqueous phase for 12 of 15 samples. Results obtained for NOTL samples indicated that the aqueous phase accounted for 98 percent of the total dieldrin concentration. Comparable results were obtained for Lake Ontario and the St Lawrence River, however, concentrations of this contaminant were found to be somewhat higher than those detected at the Niagara River stations.

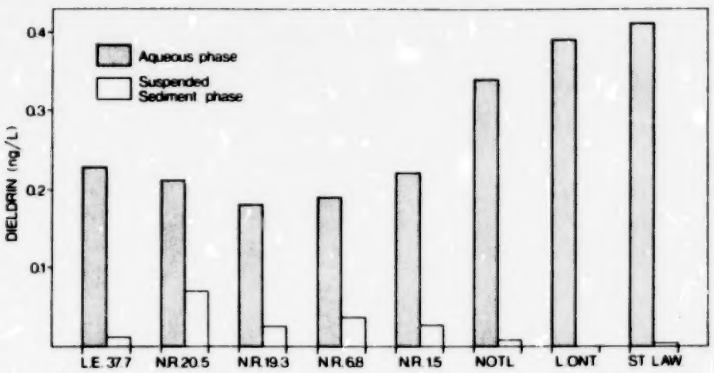

Figure 5 Distribution of Dieldrin in aqueous and suspended sediment samples from the Lower Great Lakes Region, 1981.

Endosulfan

Endosulfan exists in two stereoisomeric forms. The β-isomer was identified in the suspended sediment fraction at stations 37.7 and 20.5 with mean concentrations of .008 and .013 ng/L respectively, but it was not detected at station 19.3. Although β-endosulfan was not present at the lower Niagara River stations 6.8 or 1.5, it was found at the relatively high concentration of .25 ng/L in aqueous phase samples from NOTL. This compound was not found in Lake Ontario or the St Lawrence River.

A general increase in α-endosulfan from station 37.7 downstream to station 1.5 was detected in both phases (Fig. 6). At Lake Erie and Niagara River stations 20.5, 19.3, 6.8 and 1.5 the greater part of this contaminant was found sorbed to the suspended sediment. As in the case of β-endosulfan, the α-isomer was detected solely in the aqueous phase at NOTL. Aqueous samples from Lake Ontario and the St Lawrence River contained approximately 95 and 100 percent of the α-endosulfan present at these stations respectively.

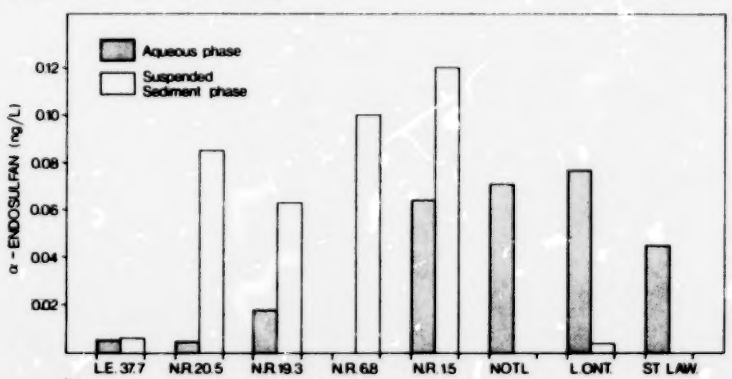

Figure 6 Distribution of α-Endosulfan in aqueous and suspended sediment from the Lower Great Lakes Region, 1981.

Endrin

Endrin was found to be most abundant in the aqueous phase at all stations. Lake Erie aqueous phase samples contained this pesticide at a concentration of .009 ng/L, however, complementary sediment samples were found to be free of the contaminant. Analyses showed that 72 and 63 percent of the compound was present in the aqueous phase at stations 20.5 and 19.3 respectively. Endrin was found exclusively in the aqueous phase at the lower Niagara River stations 6.8, 1.5 and NOTL. The mean total concentration of endrin in the Niagara River ranged from .004 to a high of .67 ng/L at NOTL. Lake Ontario and the St Lawrence River stations had concentrations of .12 and .058 ng/L, with 96 and 100 percent of the contaminant present in the aqueous component respectively.

Heptachlor epoxide

The concentration and distribution of heptachlor epoxide varied greatly from the Lake Erie station to station 1.5 on the Niagara River (Fig. 7). Elevated concentrations were detected at stations 19.3 and 1.5 with 100 percent and 95 percent of this contaminant being present in the aqueous phase respectively. Similar results were obtained for the NOTL samples where 98 percent of the contaminant was in the aqueous component. Heptachlor epoxide was not detected in Lake Ontario or the St Lawrence River.

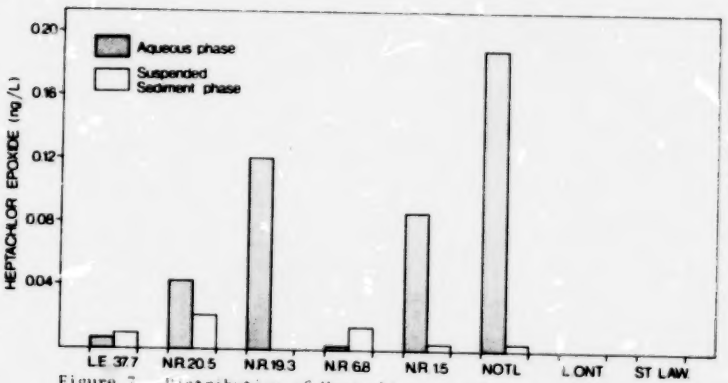

Figure 7 Distribution of Heptachlor epoxide in aqueous and suspended sediment samples from the Lower Great Lakes Region, 1981.

Methoxychlor

The distribution of p,p'-methoxychlor between the suspended sediment and aqueous phase samples from Lake Erie and the Niagara River was highly variable. At stations 37.7, 20.5, 6.8 and 1.5, low concentrations ranging from .03 to .08 ng/L were present exclusively in the suspended sediment phase. NOTL had the highest concentration of any station with a mean value of 1.1 ng/L, 48 percent of which was present in the aqueous phase. In contrast, this contaminant was found solely in the aqueous phase at station 19.3. Methoxychlor was not found in Lake Ontario or the St Lawrence River.

Mirex

Mirex was not found in Lake Erie or the upper Niagara River. Samples from stations 6.8 and 1.5 both contained .01 ng/L of mirex, with less than 5 percent of the compound existing in the aqueous phase. This contaminant was not found at NOTL or in Lake Ontario, whereas .006 ng/L was present exclusively in the suspended sediment phase of the St Lawrence River.

Total Pesticides

Percentage values for total organochlorine pesticides present in the aqueous phase derived from a summation of the individual pesticide concentrations are shown for selected stations in Table 1. The Lake Erie station 37.7 had a value of 95 percent, whereas at Niagara River stations 20.5, 19.3 and 6.8 it was found that 95, 93, and 90 percent of the total pesticides were present in the aqueous phase respectively. Aqueous percentages for stations 1.5 and NOTL were found to be quite different, with NOTL having the lowest value of all stations. Lake Ontario and the St Lawrence River had the highest mean aqueous values of 100 and 98 percent respectively.

Polychlorinated Biphenyls

At station 37.7, 100 percent of the PCB's were found in the aqueous phase (Fig. 8). The percentage of PCB's in the aqueous phase of Niagara River water decreased from 100 percent at station 20.5 to lows of 38 and 22 percent at stations 1.5 and NOTL respectively. A large increase in PCB's sorbed to suspended sediment, accompanied by a more moderate increase in the aqueous phase was detected at stations 6.8 and 1.5. PCB's found in the aqueous samples from Lake Ontario and the St Lawrence River accounted for 91 and 96 percent of the total concentration respectively.

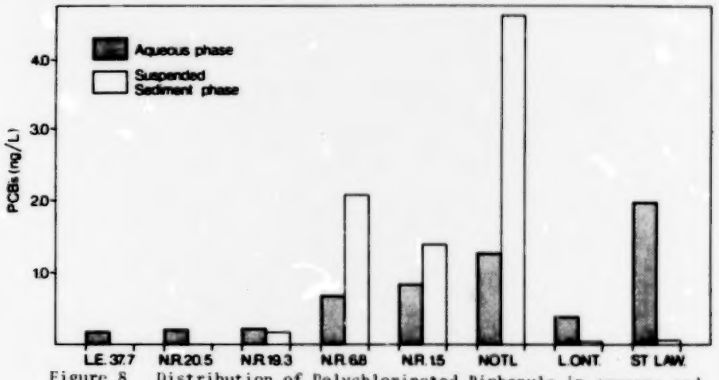

Figure 8 Distribution of Polychlorinated Biphenyls in aqueous and suspended sediment samples from the Lower Great Lakes Region, 1981.

Table 1. Summary of organochlorine contaminants at selected stations in the Lower Great Lakes Region; data is expressed as percent present in the aqueous phase.

Contaminant	Lake Erie (37.7) %	Niagara River (1.5) %	Niagara River (NOTL) %	Lake Ontario %	St Lawrence River %
Aldrin	-	-	-	-	100
α-BHC	99	99	94	100	100
γ-BHC	100	100	98	100	100
Cis-Chlordane	37	57	79	-	-
Trans-Chlordane	100	100	76	-	0
o,p'-DDT	-	-	48	-	100
p,p'-DDT	94	13	70	100	77
p,p'-DDE	7	39	49	60	38
p,p'-TDE	91	100	52	-	79
Dieldrin	94	90	98	100	99
α-Endosulfan	48	35	100	95	100
β-Endosulfan	0	-	100	-	-
Endrin	100	100	100	96	100
Heptachlor epoxide	40	95	98	-	-
Methoxychlor	0	0	48	-	-
Mirex	-	2	-	-	0
Total Pesticides[1]	95	96	78	100[2]	98
PCB's	100	38	22	91	96

Note: - denotes contaminants that were not detected in either phase.
1 %total pesticides in the aqueous phase was calculated from the sum of individual pesticide concentrations found in both phase.
2 % organochlorine pesticides were detected in the susoended sediment phase, but accounted for less than 0.5 percent of the total pesticide concentration.

DISCUSSION

An attempt was made to correlate the distribution of the organochlorine pesticides at various stations with log octanol/water partition coefficients and water solubility data (Callahan et al. 1979). It was found that no relationship existed between percent contaminant present in the aqueous phase and the above physical properties. This was not unexpected, as the lotic and lentic systems had widely different suspended sediment concentrations and there was little time for contaminants to reach equilibrium at many of the stations sampled. Although the examination of physical parameters provided little explanation for the distribution of the organochlorine contaminants, the major fraction of the total concentration of many contaminants were found in the same phase at most stations.

Mirex was found to be present almost exclusively in the suspended sediment phase at all stations where it was found. Similarly, the bulk of p,p'-DDE was found in the the suspended sediment phase. The remaining organochlorine contaminants investigated in this study were found to be most abundant in the aqueous phase at all stations or to vary greatly between the two phases.

The compounds α-BHC, γ-BHC, dieldrin and to a lesser extent, endrin, p,p'-TDE and trans-chlordane were most abundant in the aqueous phase. The distribution of p,p'-methoxychlor however, was found to vary greatly at different stations. Low concentrations of this contaminant were found to be present exclusively in the suspended sediment phase at stations 37.7, 20.5, 6.8 and 1.5, but it was found solely in the aqueous phase at station 19.3. This suggests there may have been a local aqueous input of p,p'-methoxychlor upstream of station 19.3, that had not had a chance to become sorbed to suspended sediment prior to reaching this station. Heptachlor epoxide and cis-chlordane were also found to have inconsistent distribution characteristics at different stations. The variability in distribution of these two compounds at the Niagara River stations may be due to inputs along the course of the river. Such sources of inputs may include leaching and erosion from chemical waste dumps, industrial and municipal effluents, as well as the resuspension of contaminated bottom sediments. Uncontaminated bottom sediment may also have an important effect on partitioning and distribution if it is resuspended, by providing additional sites onto which the contaminant may become sorbed.

A number of contaminants showed a general increase in a downstream direction from station 20.5 to station 1.5 on the Niagara River when the sum of their aqueous and suspended sediment components were considered. These parameters include α-BHC, γ-BHC, trans-chlordane, p,p'-DDT and α-endosulfan. This increase in the total amount of contaminant present in a downstream direction is likely due to numerous inputs along the course of the river.

An interesting trend was noted for p,p'-DDT and PCB's in the Niagara River. At station 20.5 these contaminants were most abundant in the aqueous phase. Conversely, from stations 19.3 to 1.5 the bulk of these compounds were present in the suspended sediment. The cause of this observed increase in the suspended sediment phase is not known, but may be due to the resuspension of contaminated bottom sediments or the erosion of contaminated soils. It is also possible that a shift from the aqueous to the suspended sediment phase occurs following an aqueous input: although all of the above factors may be involved.

The concentration of dieldrin present in the aqueous and suspended sediment phases remained relatively constant downstream from Lake Erie to station 1.5, suggesting that Lake Erie may be the source of this contaminant. Aldrin is readily biotransformed into dieldrin, thus its detection in the St Lawrence River indicates that there may be a local input upstream of the sampling sites.

A comparison of organochlorine contaminants present in the aqueous and suspended sediment phases at stations 1.5 and NOTL was undertaken. Water quality of these two stations should be comparable as they are in close proximity, and it has been shown that variations in water quality within this reach of the river are not significant at any one point in time (Chan, 1977). It is important to note that the NOTL samples were collected during winter when ice cover in the Eastern Basin of Lake Erie was 90-100 percent complete (Environment Canada, 1981). Such ice conditions would reduce wave action in the Eastern Basin and in turn decrease suspended sediment loads to the Niagara River.

Suspended sediment collected from January to March, 1981, as part of the IWD monitoring program at NOTL revealed that concentrations under ice cover were relatively constant with a mean of 2.8 mg/L. During open water conditions, from May to December 1981, suspended sediment concentrations were found to range from 3.1 to 23.2 mg/L with a mean value of 8.0 mg/L. This seasonal variation demonstrates that ice cover on Lake Erie plays an important role in the availability of suspended sediment to the Niagara River.

Of the contaminants investigated, only five compunds having variable distribution characteristics were present in samples from NOTL and station 1.5. Four of these compounds which include cis-chlordane,p,p'-DDT, α-endosulfan and p,p'-methoxychlor showed a shift from the aqueous phase under ice cover (NOTL) to the suspended sediment phase during open water conditions (stn 1.5). This suggests that the change in the availability of suspended sediment as a result of ice cover on Lake Erie may play a role in the distribution of several organochlorine contaminants in the Niagara River.

When ongoing water quality monitoring data collected in 1981 was further examined, an interesting relationship between suspended sediment quantity and quality emerged for the NOTL station. It was found that the concentrations of PCB's were high when the concentrations of suspended sediment were low . Conversely, when suspended sediment concentrations were high the sediment contained these contaminants at much lower levels. A statistically significant ($P \leq .05$) polynomial of the 3rd degree provided the best fit for a plot of the suspended sediment concentration in Niagara River water versus the concentration of PCB's sorbed to suspended sediment (Fig. 9).

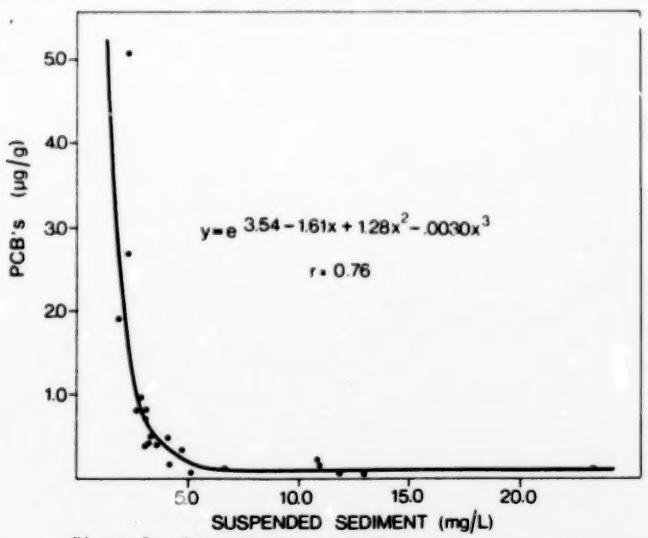

Figure 9 Concentration of PCB's sorbed to suspended sediment in relation to sediment load at Niagara-on-the-Lake (NOTL), 1981.

Most of the suspended sediment present in the Niagara River originates from Lake Erie (Kemp and Harper, 1976), and results of this study showed that suspended sediment at station 37.7 was free of PCB's. Storm events on Lake Erie may thus provide relatively uncontaminated sediment to the Niagara River, resulting in lower PCB concentrations at NOTL under high sediment load conditions. High PCB concentrations in the Niagara River when sediment loads were minimal suggests that the major source this contaminant to the river are likely located downstream of station 37.7. Such sources would include sediment from the erosion of waste disposal sites and the sorption of aqueous inputs onto the suspended sediment.

Organochlorine contaminants detected in Lake Ontario were found to be most abundant in the aqueous phase, as it contained 100 and 91 percent of total pesticides and PCB's respectively (Table 1). Lake Ontario has an average depth of 84 metres; as a result there is relatively little resuspension of bottom sediment, and suspended sediment inputs to the open lake readily settle out of the water column. With little suspended sediment present there are few sites onto which contaminants can become sorbed, thus the aqueous phase is the major carrier of trace organic contaminants in Lake Ontario surface waters. In general, the distribution of organochlorine contaminants in the St Lawrence River was similar to Lake Ontario for total pesticides and PCB's (Table 1). There was, however, a lower percentage of p,p'-DDT and p,p'-DDE in the aqueous phase relative to Lake Ontario which is likely due to an increased availability of suspended sediment in the river.

In summary, the distribution of several organochlorine contaminants varied greatly between the aqueous and suspended sediment phases, however the greater proportion of the total contaminant concentration at each station was found in the aqueous phase. This indicates that the aqueous phase should not be ignored when performing studies related to the concentration, loading and spatial distribution of organochlorine contaminants. Since the concentration and distribution of contaminants varied greatly between stations, simultaneous monitoring of both the aqueous and suspended sediment phases should provide a means for identifying major sources of organochlorine contaminants that have been previously overlooked.

ACKNOWLEDGEMENTS

The authors would like to thank R. Kwiatkowski and J. Merriman for their participation in this study. Special thanks are extended to J. Coburn and the staff of the Water Quality Branch, Ontario Region Laboratories for carrying out the chemical analyses. We would like to thank M. Head and the crew of the CSS Advent, as well as B. Moore of the National Water Research Institute for his assistance in conducting the sampling. We would also like to thank Dr. A.H. El-Shaarawi, NWRI, for computing a polynomial describing concentrations of PCB's in sediment.

REFERENCES

Callahan, M.A. et al., 1979. Water-Related Environmental Fate of 129 Priority Pollutants. U.S. Environmental Protection Agency, Report Number 440/4-79-029b, Washington, D.C.

Chan, C.H., 1980. St. Lawrence River Water Quality Surveys, 1977. Scientific Series No. 113. Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario. 1980.

Chan, C.H., 1977. Water Quality Surveys on the Niagara River - 1974. Report Series No. 48. Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario. 1977.

Environment Canada, 1981. Great Lakes Composite Ice Charts. A.E.S. 1981.

Environment Canada, 1979. Analytical Methods Manual. 1979. Inland Waters Directorate, Water Quality Branch, Ottawa, Ontario.

Frank, R., M. Holdrinet, A.L.W. Kemp, and H.E. Braun, 1979. Organochlorine pesticides and PCB in surficial sediments (1968) and sediment cores (1976) from Lake Ontario. J. Great Lakes Res. 5(1): 18-27.

Holdrinet, M., R. Frank, R.L. Thomas and L.J. Hetling, 1978. Mirex in the sediments of Lake Ontario. J. Great Lakes Res. 4(1): 69-74.

Kemp, A.L.W. and N.S. Harper, 1976. Sedimentation rates and a sediment

Kuntz, K.W., 1984. Toxic Contaminants in the Niagara River, 1975-1982. Technical Bulletin No. 134. Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario.
budget for Lake Ontario. J. Great Lakes Res. 2(2): 324-340.

Kuntz, K.W. and N.D. Warry, 1983. Chlorinated organic contaminants in water and suspended sediments of the lower Niagara River. J. Great Lakes Res. 9(2): 241-248.

Kuntz, K.W. and C.H. Chan, 1982. Water Quality of the Upper Niagara River, 1975 and 1979. Scientific Series No. 129. Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario.

McCrea, R.C. and J.D. Fischer, 1984. Design and testing of an aqueous phase liquid-liquid extractor (APLE). Inland Waters Directorate, Ontario Region, Water Quality Branch, Burlington, Ontario.

Thomas, R.L. and R.K. McMillan, 1978. Large volume water sampling for recovery of suspended solids in Great Lakes tributaries. Abstr. Int. Sedimentology Congr. p. 670.

Warry, N.D. and C.H. Chan, 1981. Organic contaminants in the suspended sediments of the Niagara River. J. Great Lakes Res. 7(4): 394-403.